

DAG-TM CONCEPT ELEMENT 11 CNS PERFORMANCE ASSESSMENT – ADS-B PERFORMANCE IN THE TRACON

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DAG-TM Concept

Distributed Air/Ground (DAG) Traffic Management (TM) is an integrated operational concept in which flight deck crews, air traffic service providers and aeronautical operational control personnel use distributed decision-making to enable user preferences and increase system capacity, while meeting air traffic management (ATM) safety requirements. It is a possible operational mode under the Free Flight concept outlined by the RTCA Task Force 3 [1].

The goal of DAG-TM is to enhance user flexibility/efficiency and increase system capacity, without adversely affecting system safety or restricting user accessibility to the National Airspace System (NAS). DAG-TM will be accomplished with a human-centered operational paradigm enabled by procedural and technological innovations. These innovations include automation aids, information sharing and Communication, Navigation, and Surveillance (CNS) / ATM technologies. The DAG-TM concept is intended to eliminate static restrictions to the maximum extent possible. In this paradigm, users may plan and operate according to their preferences - as the rule rather than the exception - with deviations occurring only as necessary. The DAG-TM concept elements aim to mitigate the extent and impact of dynamic NAS constraints, while maximizing the flexibility of airspace operations [1].

Concept Element 11

The DAG-TM concept has been divided into fifteen concept elements, of which three (CE-5, CE-6, and CE-11) are currently funded under NASA's Advanced Air Transportation Technologies (AATT) project. The solution presented in CE-11, "Terminal Arrival: Self-Spacing for Merging and In-Trail Separation" is as follows:

"Appropriately equipped aircraft are given clearance to merge with another arrival stream,

and/or maintain in-trail separation relative to a leading aircraft [2]."

In order to conduct self-spacing and maintain adequate in-trail separation, pilots need to have situational awareness of the air traffic in the airspace. This needs to be provided on the Cockpit Display of Traffic Information (CDTI) via Automatic Dependent Surveillance – Broadcast (ADS-B), supplemented by Traffic Information Services – Broadcast (TIS-B). Clearances from the air traffic control system may be either via voice or data link; Controller Pilot Data Link Communications (CPDLC) is investigated more completely in a CNS Performance Assessment due to be published later this year. Finally, pilots will also require adequate weather data provided to the cockpit via Flight Information Services – Broadcast (FIS-B); FIS-B is being researched by members of the Weather Information Communication (WINCOMM) team here at NASA Glenn Research Center..

CE-11 CNS Systems

This section provides a brief description of the CNS systems being studied as part of the DAG-TM CE-11 CNS effort at NASA Glenn Research Center. CPDLC and FIS-B are not being studied as part of the DAG-TM effort for Concept Element 11, so they are not described here. What follows are descriptions of ADS-B and the related application, TIS-B. Performance of the Mode S and UAT data links for ADS-B and TIS-B are marginal at best in the Terminal Radar Approach Control (TRACON) region where CE-11 is relevant.

Automatic Dependent Surveillance – Broadcast (ADS-B)

ADS-B is a function for airborne or surface aircraft, or other surface vehicles..., that periodically transmits its state vector (horizontal and vertical position, horizontal and vertical velocity) and other information. ADS-B is *automatic* because no external stimulus is required;

it is *dependent* because it relies on on-board navigation sources and on-board broadcast transmission systems to provide surveillance information to other users....ADS-B supports improved use of airspace, reduced ceiling/visibility restrictions, improved surface surveillance, and enhanced safety such as conflict management [3].”

Traffic Information Services – Broadcast (TIS-B)

“TIS-B is a function in which transmitters on the ground provide aircraft with information about nearby aircraft. The TIS-B information is likely to come from ground-based surveillance sensors such as air traffic control radars or multilateration systems. However, TIS-B information broadcast on a particular radio data link might also be derived from the reception on the ground of ADS-B messages that were transmitted on a different data link [3].”

Simulation Environment

It is unrealistic to study future CNS applications for Air Traffic Management (ATM) because, in many cases, the equipment has not yet been designed. In addition, the FAA certification process for equipping numerous aircraft with test equipment is rather stringent. As a result the CNS studies for DAG-TM were conducted in a modeling and simulation environment, specifically, the OPNET Modeler 9.0 simulation tool, a product of OPNET Technologies in Bethesda, MD. The traffic model used in the simulation is the LA Basin 2020 scenario described in [5] expressly for this purpose. There are nearly 3,000 aircraft simulated within a 400 nautical mile radius of Los Angeles. Approximately 30% are Class A3, 40% are Class A1, 10% are Class A2, and 20% are Class A0. The altitude and speed distribution of these aircraft is also specified in the traffic model.

Class A3 aircraft are commercial transport aircraft such as those manufactured by Boeing, Airbus, and McDonnell-Douglas. Class A2 aircraft are business jets, and the smaller jets and turboprop aircraft used by commercial airlines on routes with less traffic. Class A1 and Class A0 aircraft are typically private General Aviation (GA) aircraft operated by private pilots.

The ADS-B / TIS-B data links modeled in OPNET for this study were Mode S and UAT, the data links selected for this purpose by the FAA in July 2002 [4]. The air traffic scenario modeled in OPNET for the DAG-TM CE-11 CNS performance study was obtained from researchers at the Johns Hopkins University Applied Physics Laboratory (JHU/APL).

All of the nodes in the LA Basin traffic file were transmitting ADS-B messages. There were two Mode S scenarios and one UAT scenario. The transmitter power of the nodes in the LA Basin file varied according to the class of the aircraft [5].

Air Traffic Control Radar Beacon System (ATCRBS) is an older SSR technology utilizing Pulse Amplitude Modulation (PAM) on 1030 MHz to interrogate aircraft. Mode S is a newer SSR technology which uses DPSK to encode the data which it uses to interrogate aircraft on 1030 MHz. Replies from aircraft to ATCRBS SSRs also utilize PAM. However, replies from aircraft to Mode S interrogations use Pulse Position Modulation (PPM).

In the first Mode S scenario (designated as the ATCRBS scenario), Class A3 and Class A2 aircraft transmitted ADS-B messages, with the rates dependent on whether they were in the air or on the ground, as per [3], and also transmitted replies to SSR using the newer Mode S technology. Class A1 and Class A0 aircraft did not transmit ADS-B. They only transmitted replies to SSR using the older ATCRBS technology. Class A3 and Class A2 aircraft replied to TCAS interrogations using Mode S, while Class A1 and Class A0 aircraft replied to TCAS using an ATCRBS message format.

In the second Mode S scenario (designated 100% Mode S), all aircraft transmitted ADS-B and all aircraft transmitted replies to SSR using the newer Mode S technology. Replies to TCAS interrogations were also transmitted using Mode S.

In the UAT scenario, the pattern of messages transmitted varied according to the class of the aircraft, as per RTCA DO-282. Replies to SSR do not play a role in the UAT interference environment. Military JTIDS transmissions may interfere with UAT, however JTIDS was not modeled in the OPNET simulation.

In addition to the transmitting aircraft and ground nodes in the LA Basin 2020 traffic file, five receiver nodes, with the sensitivity of Class A3 aircraft, were modeled for the CE-11 study in OPNET to simulate traffic in the TRACON. One stationary node was modeled at an altitude of 5000 feet at the center of the LA Basin. This node will hereafter be referred to as “Node CTR”. Four other nodes were modeled, offset from the center by 50 miles each in the north / south and east /west directions approaching the center of the LA Basin from the corners along northeast, northwest, southeast, and southwest bearing. These aircraft will hereafter be referred to as Nodes NE, NW, SE, and SW, respectively.

These receivers were traveling at 200 knots (groundspeed) and descending at a rate of 1000 feet per minute, starting at an initial altitude of 10,000 feet. The simulation runs were for ten minutes of flight time each. Further details of the OPNET ADS-B models, including Mode S and UAT assumptions, and the characteristics of aircraft nodes transmitting ADS-B can be found in [6].

Simulation Results

1090 MHz Extended Squitter with ATCRBS interference

Figure 1 shows the performance of ADS-B in the presence of replies to ATCRBS Secondary Surveillance Radars (SSR). (The horizontal axis of all the figures in this paper represent time in minutes.) Class A3 and Class A2 aircraft transmit ADS-B and reply to Mode S interrogations from SSRs. Class A1 and Class A0 aircraft in the scenario do not transmit ADS-B but do reply to ATCRBS SSR interrogations.

The rate of replies to older ATCRBS SSRs is much higher than the rate of reply to newer Mode S SSRs, and therefore increases the interference environment faced by ADS-B. The top graph of Figure 1 shows that reception occurs out to nearly 150 miles, but the gaps in the trace show that reception is spotty. The bottom graph shows the update rate of ADS-B position messages per second. The receiver processing the ADS-B messages in Figure 1 is Node SE. The duration of

the descent from 10,000 feet to ground is 10 minutes, and the speed, once again, is 200 knots.

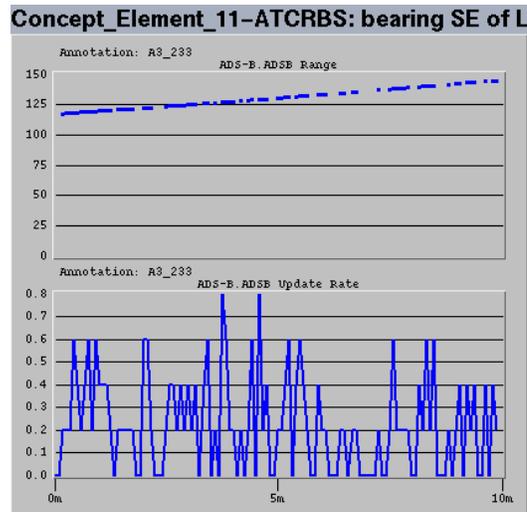


Figure 1. CE-11 ADS-B Performance in an ATCRBS environment

If 100% of 1090 MHz Extended Squitter (ES) ADS-B messages got through to the receiver, the update rate of position messages from a single aircraft would be 2 messages per second. (The update rate for all ADS-B messages combined is 6.2 messages per second.) The lower graph shows update rates of 0.2 and 0.4 messages per second most of the time, a few instances where the update rate is 0.6, and two where the update rate is 0.8. Assuming a (generous) average of 0.4 messages per second received, only 20% of the ADS-B messages that are broadcast from the aircraft in question are received. Only updates of position messages are shown; however, the statistic can be extrapolated to all ADS-B messages. We see that 20% of position messages are successfully received. Other ADS-B messages are also transmitted in the simulation at rates specified in RTCA DO-260A, since they also contribute to the signal environment. Since the receiver treats all ADS-B messages equally, we can infer that if only 20% of position messages are successfully received, the same is true for other types of ADS-B messages as well. Clearly when ATCRBS interference is present, the performance of ADS-B in the TRACON is unacceptable for DAG-TM Concept Element 11.

1090 MHz ES ADS-B in a 100% Mode S Environment

The previous section demonstrated that the presence of ATCRBS interference severely degrades the performance of 1090 MHz ES ADS-B. For a more complete description of this problem see [6].

In an effort to improve the performance of 1090 MHz ES ADS-B, which is the data link chosen for ADS-B transmission by the FAA for commercial airlines, a scenario was examined where it was assumed that all of the aircraft in the LA Basin, irrespective of class were equipped with Mode S transponders, with which to reply to interrogations from ground based SSRs. Since 100% Mode S equipage was postulated, it was also assumed that all aircraft would transmit ADS-B using 1090 MHz ES, which makes use of the Mode S transponder. Since all aircraft were equipped with Mode S, there would be no replies to ATCRBS SSRs on 1090 MHz. Furthermore, since all aircraft were broadcasting ADS-B, and doing so using the same data link, there would be no need for TIS-B transmissions either. As early as 2001 the Technical Link Assessment Team (TLAT) that was evaluating three competing links for ADS-B (1090 MHz ES, UAT, and VHF Digital Link (VDL) Mode 4) concluded that when 100% of aircraft were transmitting ADS-B, that would provide greater traffic on the communications link than when a combination of ADS-B and TIS-B was being transmitted [7].

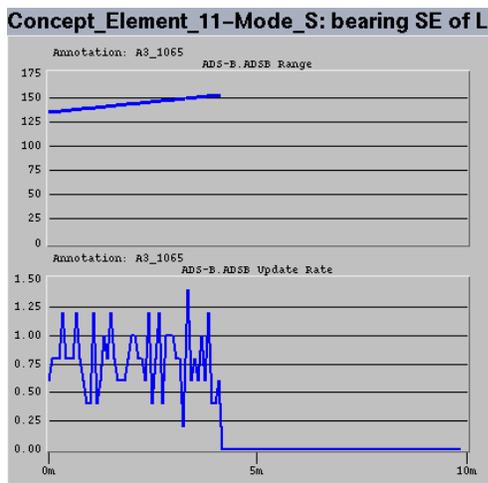


Figure 2. CE-11 ADS-B Performance in a 100% Mode S environment (Class A3 aircraft)

In the 100% Mode S environment shown in Figure 2, ADS-B messages are received by Node SE, from a Class A3 aircraft (A3_1065) even slightly more than 150 miles away. In all of the graphs displaying the range to the transmitting aircraft, it is the maximum range at which signals are received which is of interest to us. The minimum range at which signals from aircraft are received is more a function of the relative distance between transmitter and receiver when the simulation started and not of anything more substantive. Position messages in Figure 2 are received between 0.75 to one message per second, which corresponds to an update rate of 37% to 50%, indicating that interference from other Mode S and ADS-B transmissions is a problem.

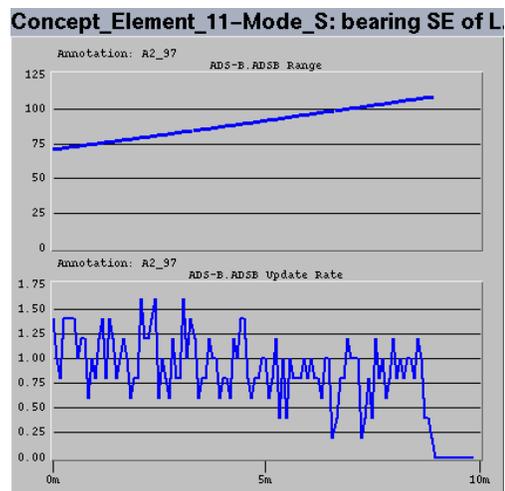


Figure 3. CE-11 ADS-B Performance in a 100% Mode S environment (Class A2 aircraft)

Figure 3 shows similar results when the ADS-B signal is coming to Node SE from a Class A2 aircraft. In this case signals are received out to a range of nearly 110 miles, but with a similar spotty performance of the update rate, as can be seen in the lower graph. However, at ranges up to 90 miles, the reception rate is sometimes as good as one and a quarter messages per second for a 60% update rate. Results similar to those in Figures 2 and 3 were observed at the center of the LA Basin as well.

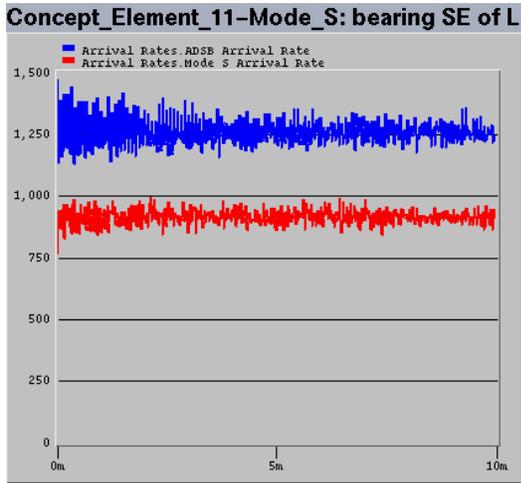


Figure 4. ADS-B and Mode S SSR reply arrival rates in 100% Mode S environment

Figure 4 illustrates the total number of ADS-B packets (upper trace) and Mode S packets (lower trace) received on a per second basis at the receiver descending to the center of the LA Basin along a southeasterly bearing. Roughly 1,250 ADS-B messages are seen every second. With aircraft transmitting 6.2 messages per second on 1090 MHz ES, this means that at any given time the receiver sees a little over 200 aircraft in the vicinity.

The signal to noise ratio (SNR) shown in Figure 5 is at an average of 11.1 dB. This indicates that roughly thirteen 1090 MHz messages get through for every one that is interfered with. This SNR is a composite value. Not only are ADS-B messages received, but also replies on 1090 MHz to Mode S SSR interrogations. The SNR only indirectly plays a role in determining the number of ADS-B packets and Mode S SSR replies which are successfully received as seen in Figure 4. This is because the OPNET simulation did not model packet loss based on the bit error rate (BER). Rather, if there is more than one interfering packet within +/- 6 dB the packet in question is assumed to be lost [6]. This is because the interference environment is not Gaussian, and standard modulation curves relating SNR to BER cannot be used. The +/- 6 dB figure was based on experiments run by MIT Lincoln Laboratories when they were developing Mode S technology.

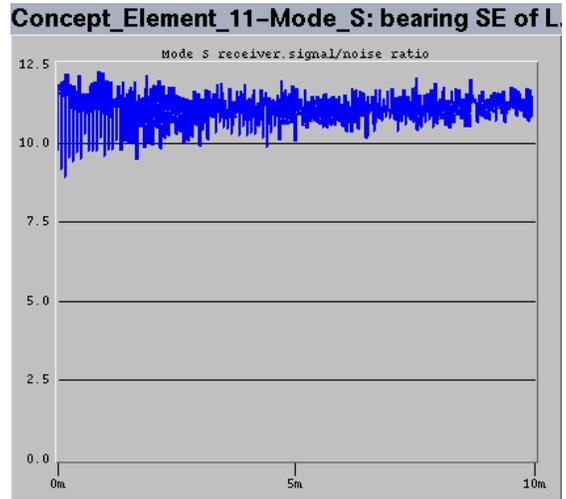


Figure 5. Signal-to-Noise Ratio, 100% Mode S environment

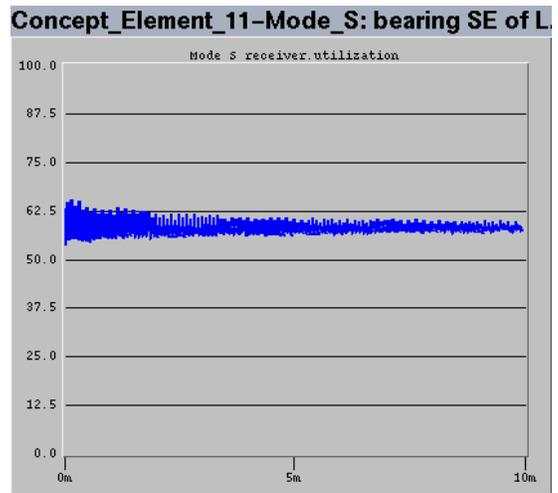


Figure 6. Mode S receiver utilization

The final statistic shown for the 1090 MHz simulations is the percentage of time the Mode S receiver is busy processing packets, or in other words, the receiver utilization. Even without the presence of ATCRBS the receiver is busy roughly 60% of the time. This does indicate room for growth beyond the LA Basin 2020 scenario TRACON capacity, although we must recall that our earlier graphs of Class A3 and Class A2 aircraft ADS-B update rates, while generally good, were also somewhat spotty. Basically this means that performance is likely to drop further, with increased traffic, even before the full capacity of the receiver is reached.

ADS-B using the UAT data link

Figure 7 depicts the range of reception for Node SE in the UAT scenario. Five different aircraft are being tracked, and the range at which UAT ADS-B messages are received from them is clearly not consistent. It is not clear why this is the case, although one theory is suggested.

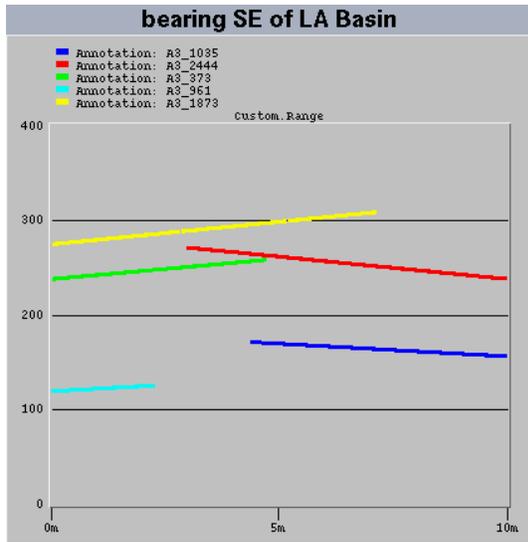


Figure 7. UAT ADS-B Reception Ranges

The time at which an aircraft equipped with UAT transmits an ADS-B message is based on the 12 least significant bits (LSBs) of (alternately) the latitude or the longitude. 360 degrees of longitude are represented by 24 bits. 180 degrees of latitude are represented by 23 bits. Therefore the 12 LSBs of the latitude and longitude represent 0.0879 degrees. In the LA Basin, this corresponds to 5 miles east / west (longitude) or 6 miles north / south (latitude). Within these intervals, aircraft do not interfere with each other when transmitting ADS-B.

It is surmised that the density at which the location of aircraft repeats every five miles of longitude or six miles of latitude varies in the LA Basin. In other words the number of aircraft whose position corresponds to the same 12 LSBs of latitude or longitude varies throughout the LA Basin for different values of these 12 LSBs. Therefore, the range at which UAT ADS-B is received varies from over 300 miles out to less than 150 miles out.

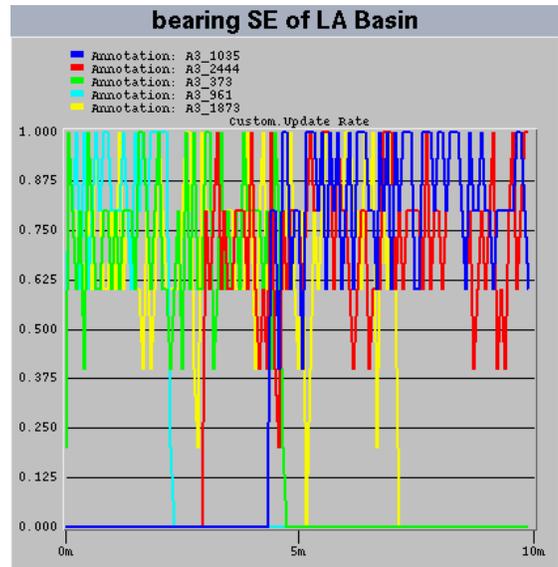


Figure 8. UAT ADS-B Update Rates

UAT ADS-B messages are transmitted at a rate of one per second. The reception rates, shown in Figure 8, from five Class A3 aircraft seen by Node SE, vary from 60% to 100%, for perhaps an average update rate of 80%. This average update rate corresponds to what has been observed in an earlier en route study for DAG-TM Concept Element 5. [6] This is clearly better than the performance for Mode S, although it isn't perfect.

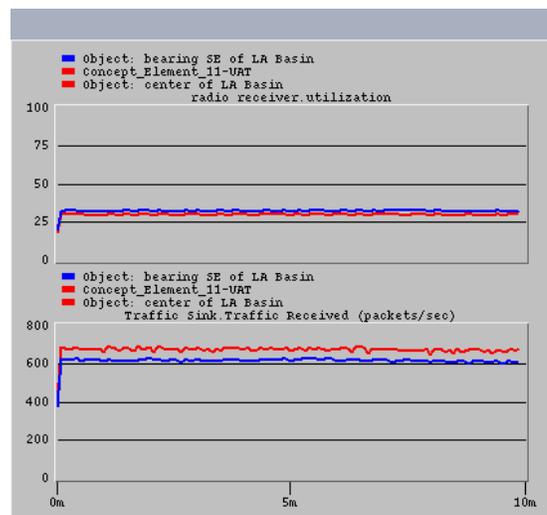


Figure 9. UAT Receiver Utilization and Received ADS-B Traffic

Figure 9 reinforces that there is capacity for growth as well. The current utilization of the UAT ADS-B receiver, both at Node SE and at Node CTR

is only around 30%. Between 600-700 messages are received every second (meaning messages from 600-700 aircraft) with more messages received at the receiver at the center, despite the (slightly) higher traffic density. The traffic density near the center receiver is only slightly higher since we are already focusing on the TRACON around LAX and not on the entire LA Basin.

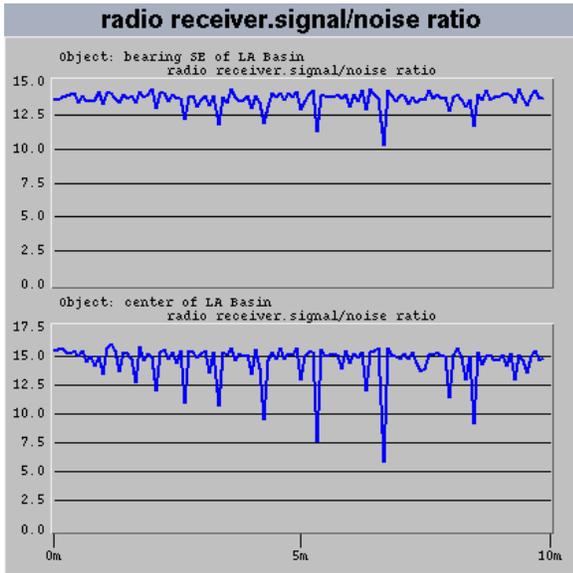


Figure 10. UAT Signal-to-Noise Ratio

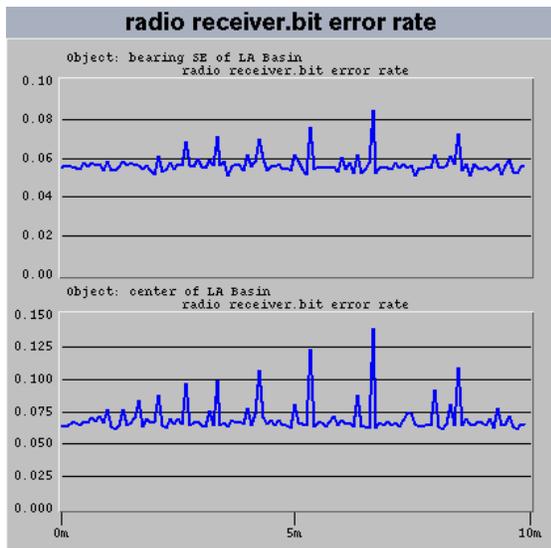


Figure 11. UAT Bit Error Rate

Figures 10 and 11 show the Signal-to-Noise Ratio (SNR) and the Bit Error Rate (BER) of UAT ADS-B, both at the center of the TRACON and at

Node SE. At the latter, the SNR is 13.85 dB; at the center of the LA Basin, the SNR is 15 dB. However, there are more deep fades at the center of the LA Basin. The BER, which is computed from the SNR based on an MSK (CPFSK) modulation curve, reflects this. Despite the BER being consistently under the 10% error correction threshold set in the OPNET receiver module, the actual reception is still not perfect (in terms of update rate) since errors are allocated statistically based on the BER, and can be more than 10% for a given packet. For a discussion of how the error correction threshold was set, see [6].

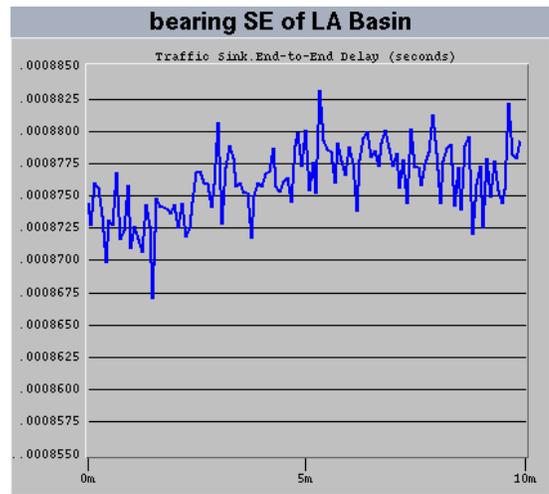


Figure 12. End-to-End Delay

Finally, Figure 12 shows that the end to end delay from transmission to reception of UAT ADS-B packets, not counting on-board processing time, is between 870 and 880 microseconds for the receiver with the southeasterly bearing. The ETE Delay was slightly less at the center of the LA Basin. The ETE Delay shown in this graph demonstrates that there is plenty of margin to add onboard processing delays before bumping up against the latency ceilings of 0.4 seconds with 95% confidence promulgated in [5].

Conclusions

From our study of 1090 MHz ES ADS-B, we see that the performance when ATCRBS interference is present, is unacceptably low. In a 100% Mode S environment, the performance is marginal. Only 40% of ADS-B messages from Class A3 aircraft are received, although they are

received out to a range of 150 miles. Reception from Class A2 aircraft is slightly better, with roughly 50% of messages received out to 90 miles, and 40% of messages received out to 110 miles. The SNR of the 1090 MHz link demonstrates that a dozen transmissions get through for every one that is interfered with. However, many of these transmissions are replies to ground-based radar from aircraft in the vicinity of the receiver, and are not ADS-B messages. Receiver utilization is not an issue for 1090 MHz ES ADS-B, with plenty of spare capacity.

UAT ADS-B presents a more interesting picture. The range at which ADS-B transmissions are received vary widely even among Class A3 transmitting aircraft. However, in all cases the update rate is around 80% which is rather good. UAT receivers in the LA Basin TRACON can see over 600 nearby aircraft. (UAT messages are transmitted from aircraft once per second, and the rate at which traffic is received at the receiver is over 600 messages per second.) This is much better than the performance of 1090 MHz ES. As with 1090 MHz ES, receiver utilization in UAT is not an issue. However there are deep fades in the SNR at the center of the LA Basin.

On board processing delays were not considered in the ADS-B simulations using the 1090 MHz ES and UAT data links. Regardless, the performance of 1090 MHz Extended Squitter ADS-B is marginal in the TRACON; the performance of UAT ADS-B varies according to parameters that were not fully understood through the use of the OPNET simulation tool. ADS-B technology needs to be improved or rethought prior to its use to support DAG-TM Concept Element 11.

References

- [1] <http://www.asc.nasa.gov/aatt/dag.html>
- [2] AATT Project, Airspace Systems Program, NASA, 1999, "Concept Definition for Distributed Air/Ground Traffic Management, Version 1.0", p.34.
- [3] RTCA, 2003, "Minimum Operational Performance Standards for 1090 MHz Extended

Squitter ADS-B and TIS-B", DO-260A, Volume 1, p. 3.

[4] FAA Office of Public Affairs, 2002, *FAA Announces ADS-B Architecture*, APA 27-02, Washington, DC.

[5] RTCA, 2002, "Minimum Aviation System Performance Standards for ADS-B", DO-242A, p.100-101.

[6] Raghavan, Rajesh, Mohammed Shamma, 2003, "DAG-TM Concept Element 5, CNS Performance Assessment for Free Maneuvering", Analex Corporation at NASA Glenn Research Center, Cleveland, OH.

[7] ADS-B Technical Link Assessment Team, 2001, "Technical Link Assessment Report", Washington, DC, Federal Aviation Administration, p. 14.



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ADS-B Performance in the TRACON for DAG-TM Concept Element 11

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- Description of ADS-B
- Description of DAG-TM Concept
- OPNET Modeling Environment
- Simulation Parameters
- Simulation Results
- Discussion

- Automatic Dependent Surveillance - Broadcast
- Defined in RTCA DO-242A
- Position, velocity, and status information broadcast from aircraft at regular intervals using information obtained from Global Positioning System (GPS) Satellites and onboard systems
- July 2002 Data Link Decision by FAA
 - High performance and commercial aircraft will use Mode S
 - General aviation will equip with Universal Access Transceiver (UAT)
 - Equipage is optional but equipped aircraft will have the increased situational awareness necessary for Free Flight.

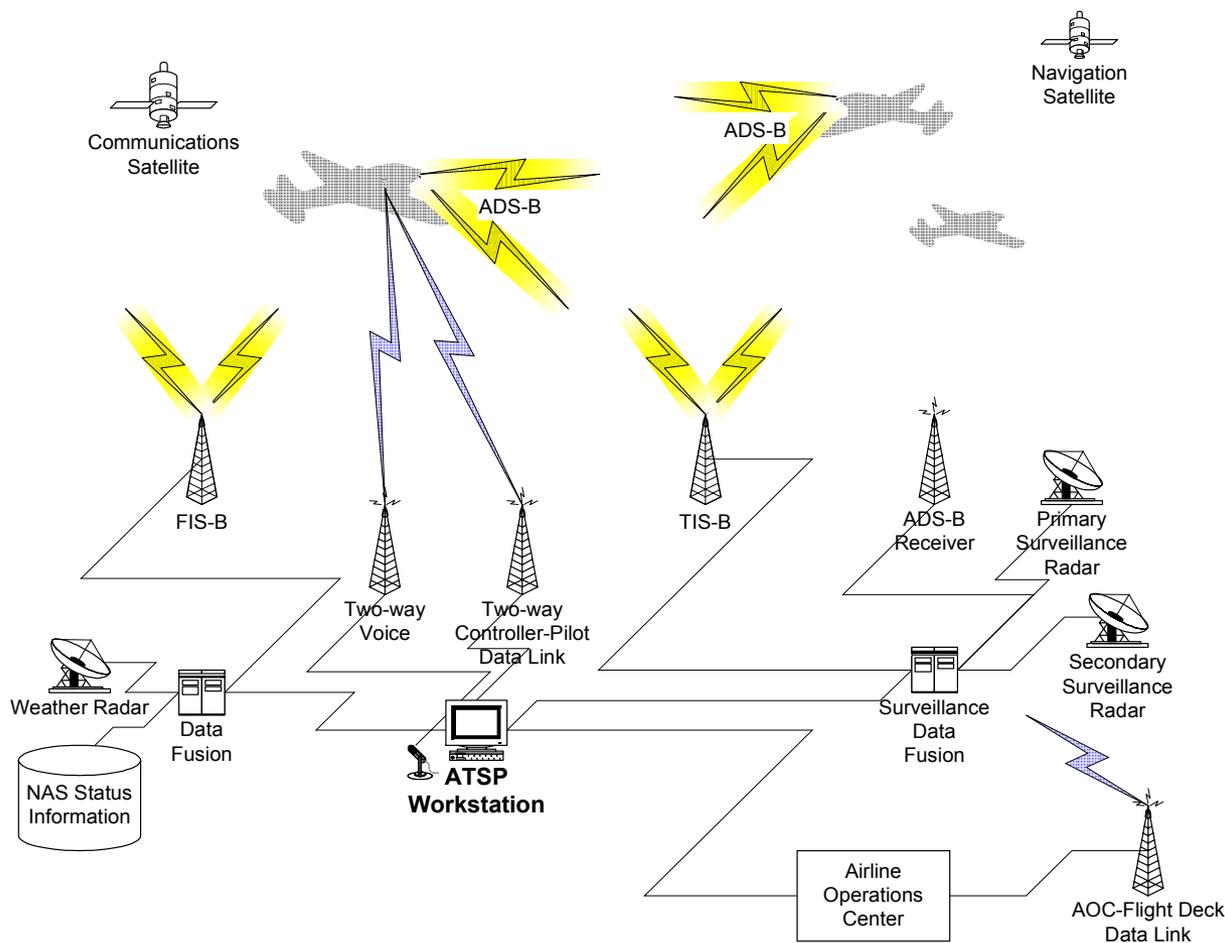
- Distributed Air/Ground Traffic Management (DAG-TM) is part of the Advanced Air Transportation Technologies (AATT) Project in the NASA Airspace Systems Program.
- Flight crews, air traffic personnel, and airline operational centers will use distributed decision-making to enable user preferences and increase system capacity.
- For the purpose of NASA research into feasibility, DAG-TM has been divided into fifteen concept elements
 - CE-5, CE-6, and CE-11 are currently funded under AATT
 - This presentation focuses on the use of ADS-B in Concept Element 11.

- Concept Element 11 is Terminal Arrival:
 - Self-spacing for Merging and In-Trail Separation
- “Appropriately equipped aircraft are given clearance to merge with another arrival stream, and/or maintain in-trail separation relative to a leading aircraft.”

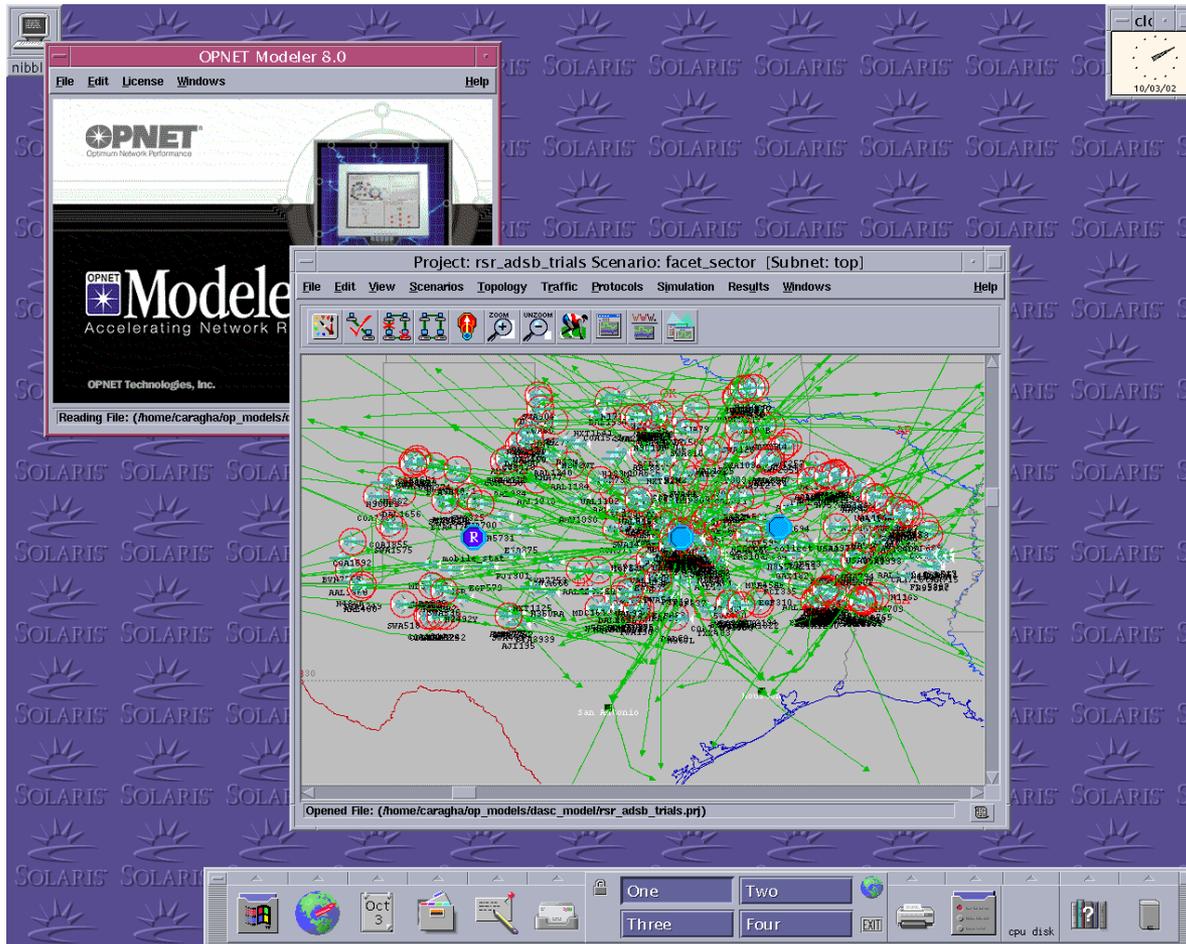
- Concept Element 11 of DAG-TM is envisioned to exist in the TRACON.
- Aircraft operating in the DAG-TM Concept of Free Flight will primarily be commercial and high performance GA aircraft
- Mode S technology was developed at MIT Lincoln Labs for use in Secondary Surveillance Radar.
- ADS-B makes use of the data link capabilities in Mode S
- Mode S Documentation
 - RTCA DO-181C
 - RTCA DO-260A (1090 MHz (Mode S) ADS-B and TIS-B)

- Although the FAA has chosen Mode S as the ADS-B data link for high performance aircraft, such as those that would benefit from the DAG-TM Concept, UAT is studied as an alternate due to limitations in the Mode S data link.
- The UAT data link for ADS-B, developed by MITRE is described in RTCA DO-282.

DAG-TM Surveillance Environment



OPNET Modeling Environment



OPNET Simulation Parameters – LA Basin 2020 scenarios

- LA Basin 2020 traffic file provided to NASA Glenn by researchers at Johns Hopkins Applied Physics Laboratory; file conforms to ADS-B traffic scenario in RTCA DO-242A
- SSRs assumed to be dual-mode Mode S / Monopulse ATCRBS
- Different classes of aircraft have different transmitter power. There is also a class for ground vehicles. ADS-B message distribution corresponds to RTCA DO-260A (draft).
 - In scenario with ATCRBS, Class A3 and A2 aircraft transmitted 1090 MHz ES ADS-B and replied to Mode S interrogations. Class A1 and A0 replied to ATCRBS interrogations.
 - In the other Mode S scenario, 100% of aircraft were Mode S equipped and transmitted ADS-B. No ATCRBS replies. Hence no TIS-B traffic.

OPNET Simulation Parameters – LA Basin 2020 scenarios (cont.)

- Receiver aircraft collecting statistics had Class A3 MTL for transponder. One stationary at center of LA Basin at altitude of 5,000 feet. Four others, offset 50 miles north / south and east / west from center at 10,000 feet, descending 1,000 feet / minute.
- Reply rates to ground-based Mode S and ATCRBS radars determined based on numbers cited in 2000 FAA LA Basin report.
- ADS-B transmissions, Mode S replies, ATCRBS replies, and TCAS signaling were all on 1090 MHz.
- ADS-B messages on 1090 MHz ES above Class A3 MTL were successfully received unless interfered with by MORE THAN one other packet within +/- 6 dB during reception.

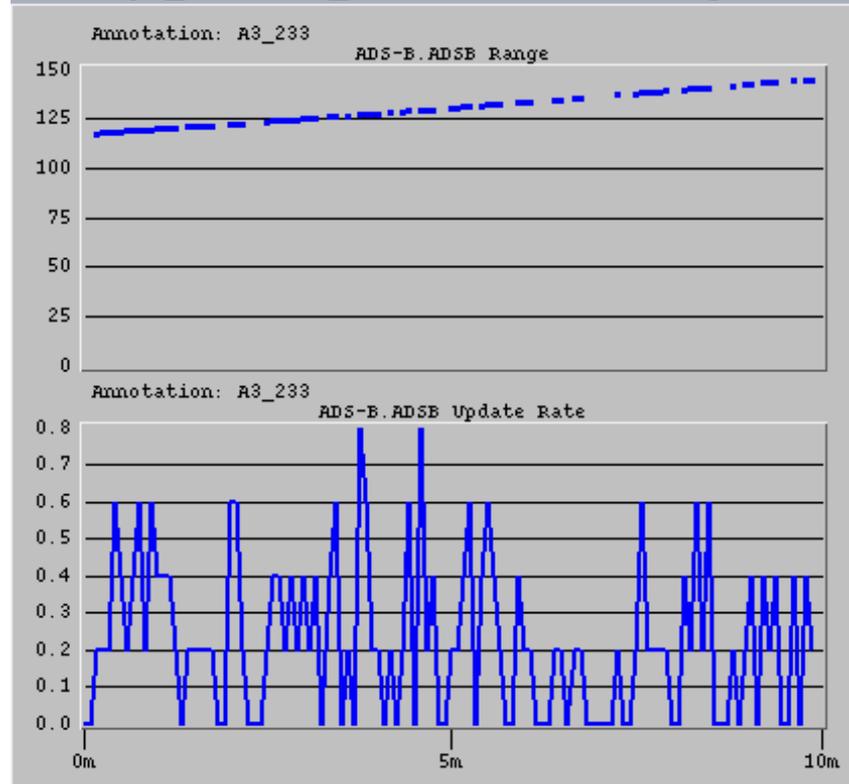
OPNET Simulation Parameters – LA Basin 2020 UAT Scenario



- Same distribution of transmitting nodes was used in UAT scenario as in Mode S scenarios.
- Receiver nodes were also Class A3 and similarly located
- Interference from DoD JTIDS communication system was NOT modeled
- UAT messages are transmitted once per second at varying times within the one second frame. The type of message transmitted varies based on the aircraft class over a 16 second interval
- Error rate of received packets is calculated from SNR based on CPFSK modulation curve

LA Basin 2020 Update Rate ATCRBS Scenario

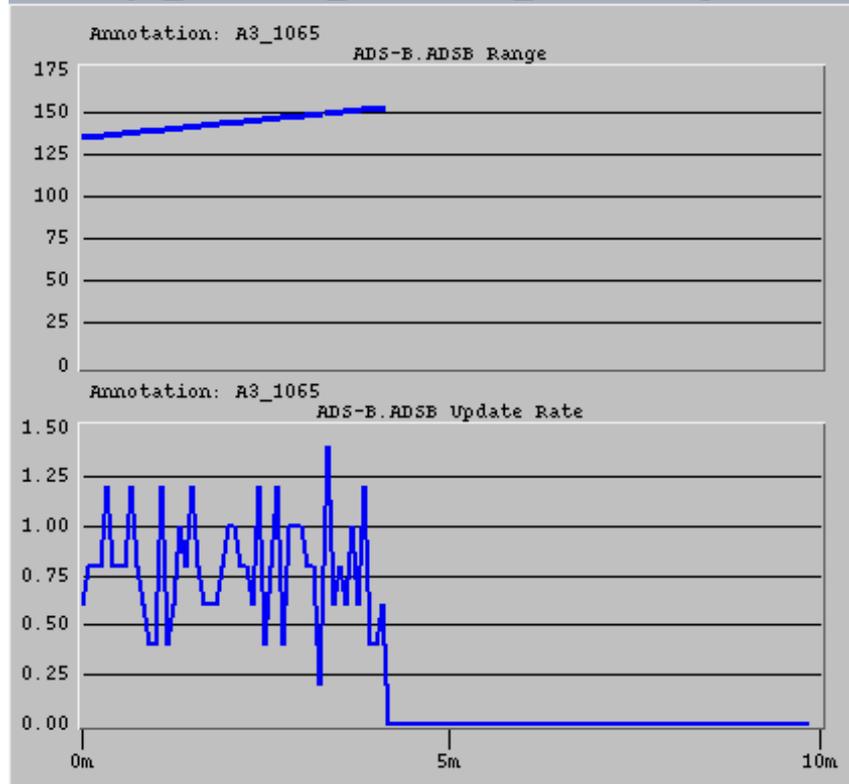
Concept_Element_11-ATCRBS: bearing SE of L



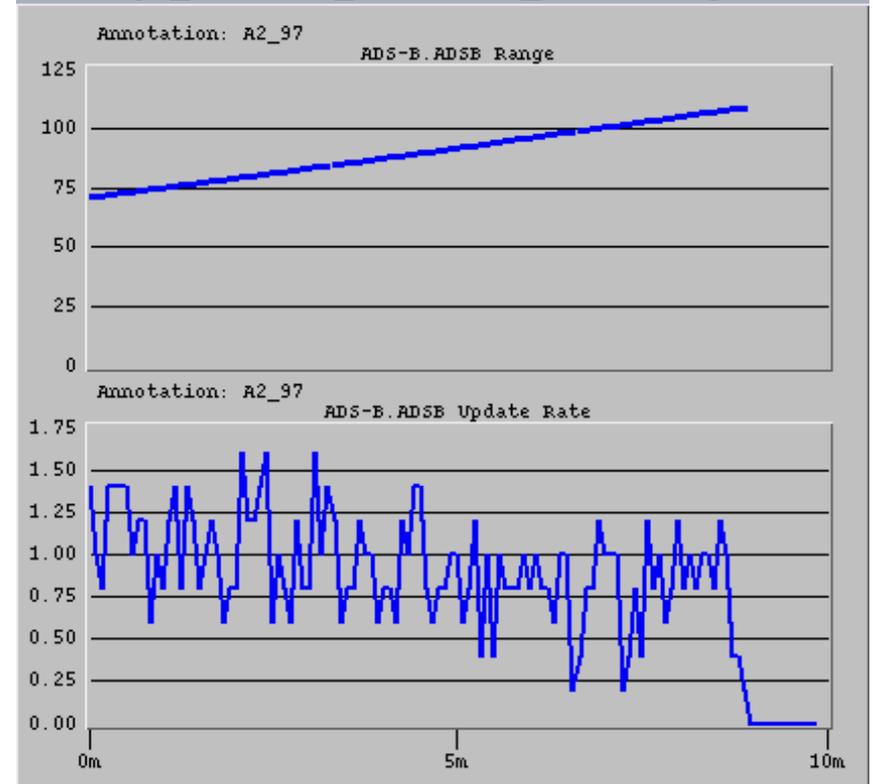
- Messages are received at ranges beyond 125 miles
- However only an average of 0.4 messages are received per second
- Full reception would be 2 messages per second
- Only 20% of messages are received
- Performance of 1090 ES ADS-B with ATCRBS interference is unacceptable

LA Basin 2020 Update Rate 100% Mode S Environment

Concept_Element_11-Mode_S: bearing SE of L.

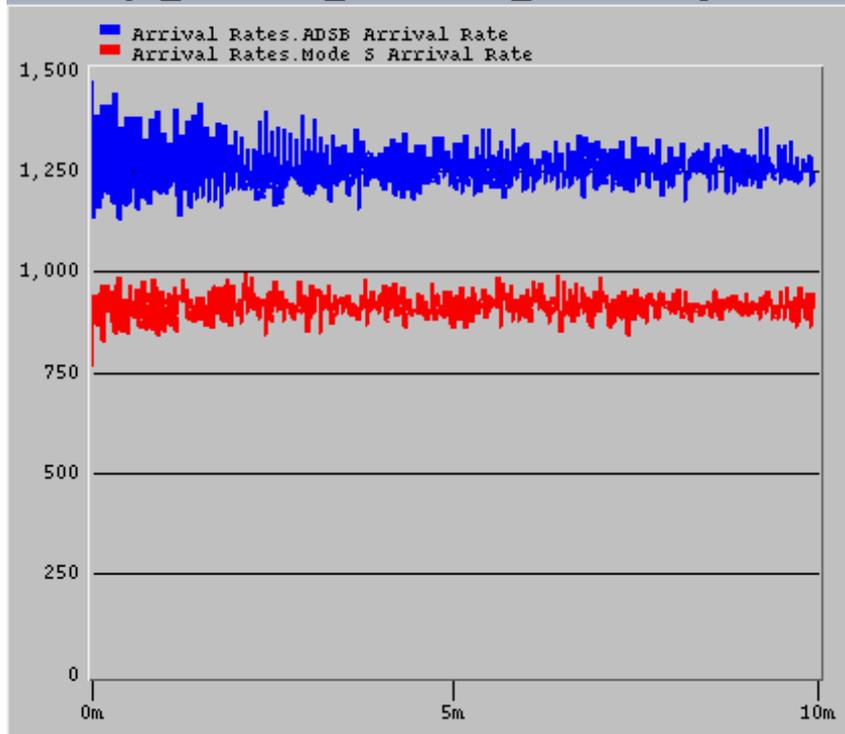


Concept_Element_11-Mode_S: bearing SE of L.



LA Basin 2020 Results 1090 MHz Arrival Rates

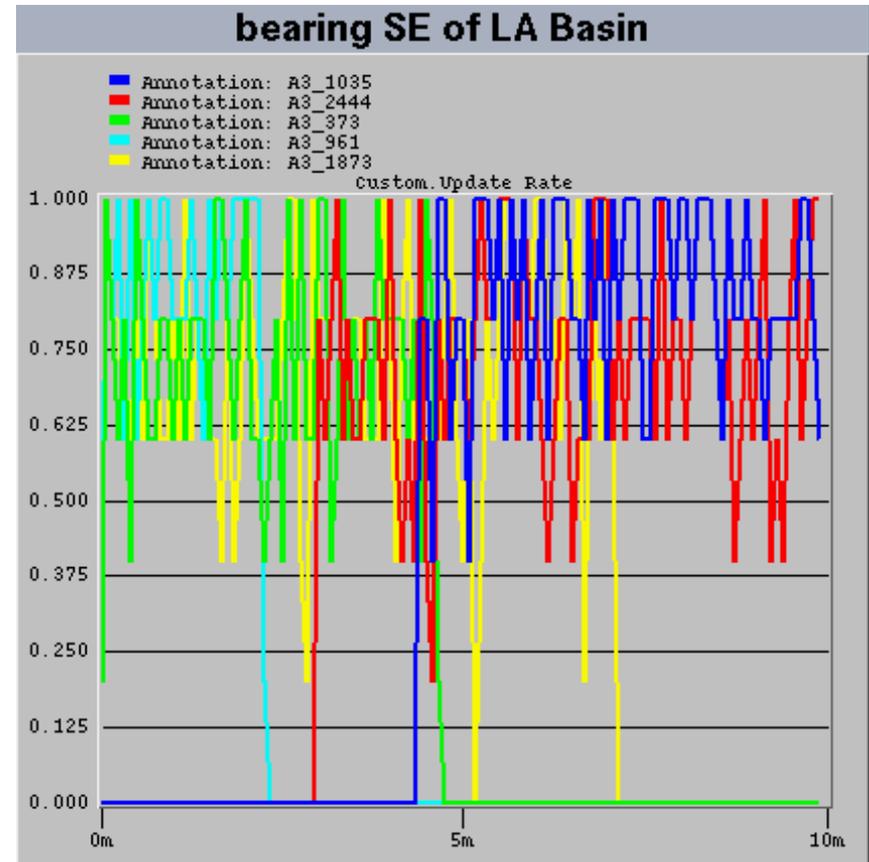
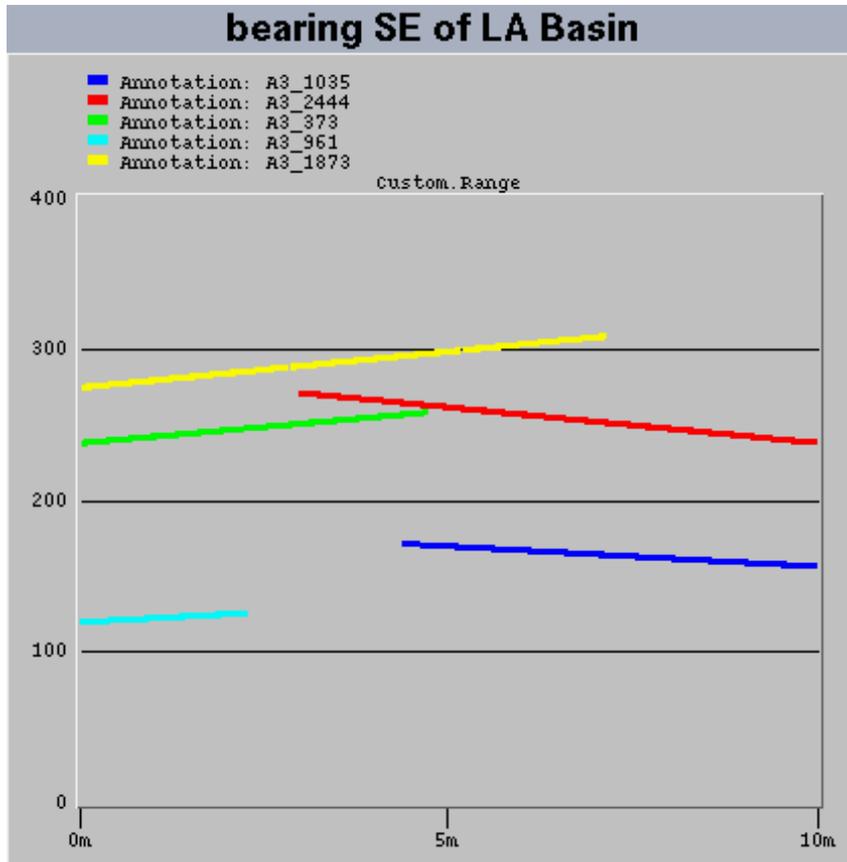
Concept_Element_11-Mode_S: bearing SE of L.



- Roughly 1250 ADS-B messages are received per second.
- Aircraft transmit at 6.2 messages per second
- Hence roughly 200 aircraft are visible to the receiver at any given time.

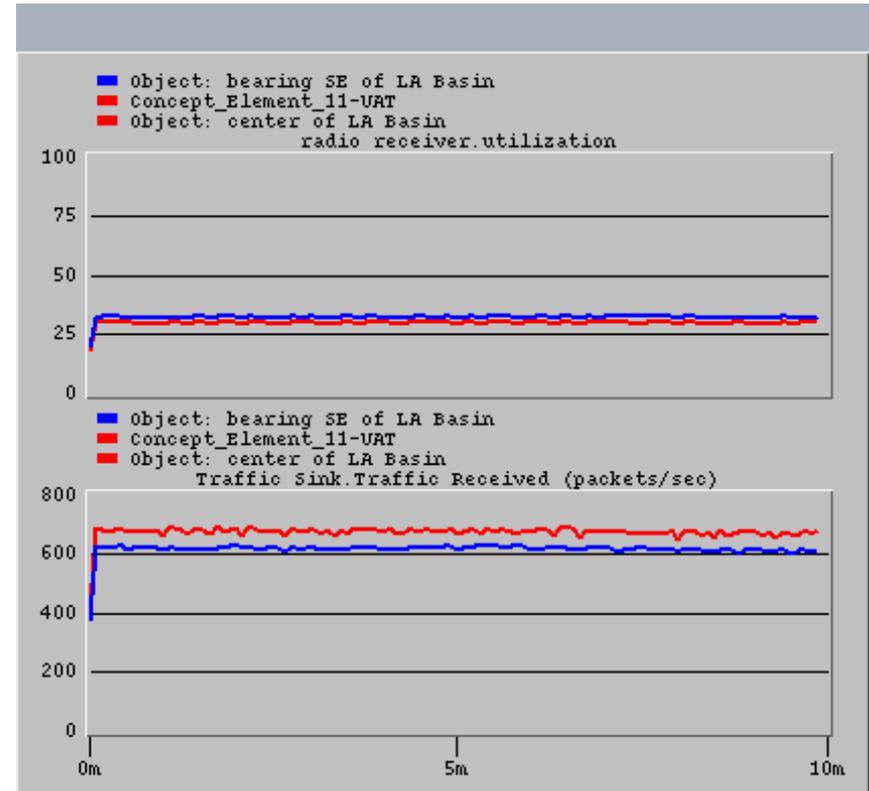
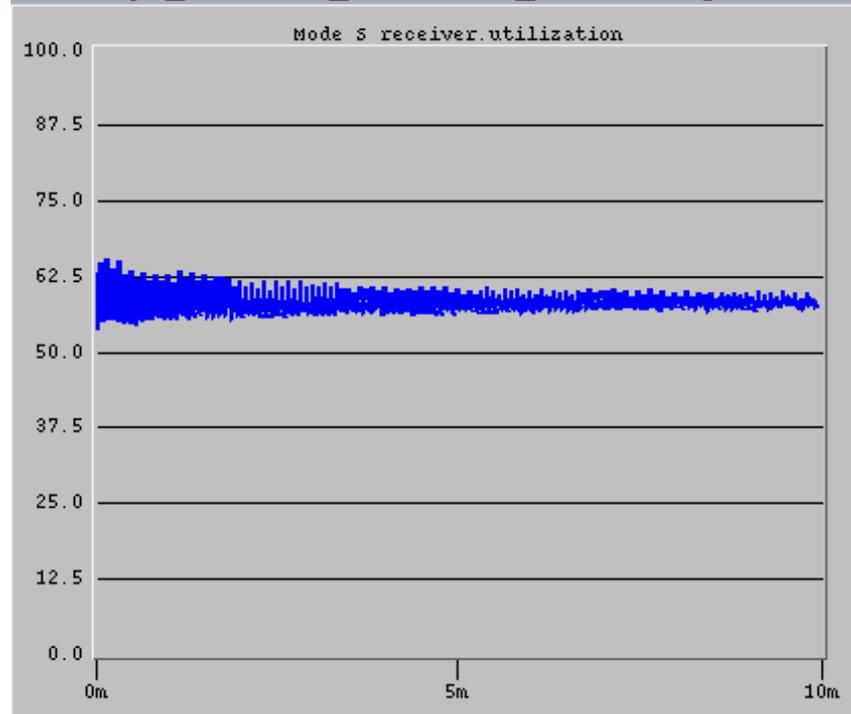
LA Basin 2020 Results

UAT Ranges & Update Rates



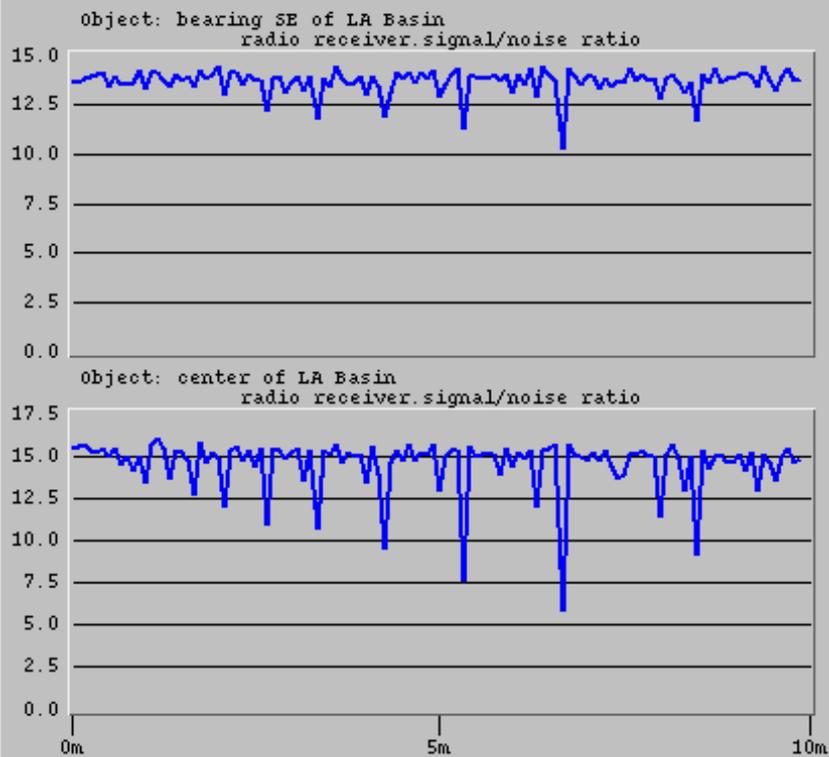
LA Basin 2020 Receiver Utilization

Concept_Element_11-Mode_S: bearing SE of L.

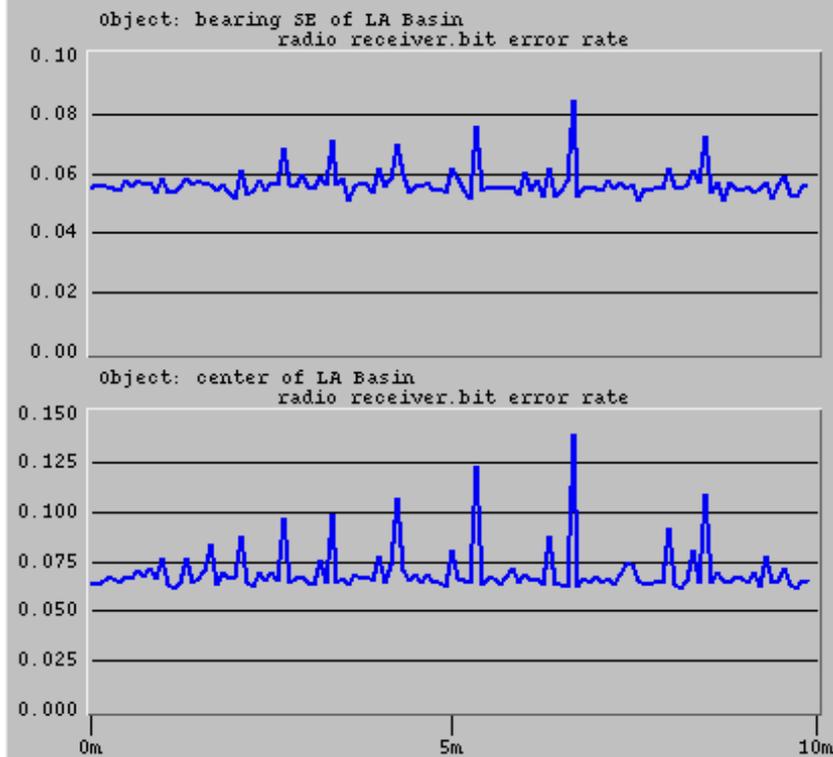


UAT SNR & BER

radio receiver.signal/noise ratio



radio receiver.bit error rate



Assumptions and Limitations

- The true interference environment has been observed to be non-Gaussian based on MIT Lincoln Laboratories flight tests in the LA Basin in 1999. The approximation (multiple interferers within +/- 6 dB) was suggested to the author by Jon Bernays of the ATC group at MIT Lincoln Labs.
- The OPNET model used isotropic antennas instead of top/bottom mounted omnidirectional antennas specified in RTCA DO-181C and DO-282.
- If an aircraft is Mode S capable, the model assumed it would be interrogated as such. In reality older ATCRBS SSRs may interrogate it, increasing the ATCRBS traffic present.
- To improve simulation speed, TCAS interrogations and SSR interrogations were not explicitly modeled. TCAS replies assume a constant maximal interrogation rate, and the nature of SSR interrogations was based on the number of ground sites observed by MIT Lincoln Laboratories in their 1999 LA Basin study.

Assumptions and Limitations (cont.)

- Ground (zero altitude) receivers for ADS-B were not modeled, although they could have been.
- Although there was a transmission delay in addition to the free space propagation delay, and although simultaneous 1090 MHz messages within a node get queued for transmission, the onboard processing delay within the FMS was not modeled, due to a lack of information on how to do so.
- Interference from 1030 MHz transmissions were not included, because based on the OPNET interference model, they would not affect 1090 MHz reception.
- JTIDS transmission would interfere with UAT signals somewhat, but were not modeled, since military traffic is not always present, and since JTIDS uses a frequency hopping algorithm anyway.

Acknowledgments



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Conclusions and Future Directions

- 1090 MHz ES ADS-B performance in the TRACON is unacceptable in an environment including ATCRBS SSRs; however, the performance is somewhat improved in a 100% Mode S environment
- The ranges at which UAT ADS-B messages are received vary greatly, probably based on the local density of the aircraft. Aircraft within 12 LSBs of latitude or longitude do not interfere with each other, but aircraft whose 12 LSBs repeat (aircraft in different clusters) would interfere.
- The Signal-to-Noise Ratio for UAT exhibits more deep fades at the center of the LA TRACON resulting in higher bit error rates based on the CPFSK (MSK) modulation curve
- Future work would involve including JTIDS interference and more explicitly modeling the non-Gaussian nature of the interference environment